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High-Performance 1645-nm Er:YAG Laser

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This technical report has been reviewed and is approved for publication. Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

Michael Zambrana

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14. ABSTRACT

The efficiency and output of the resonantly fiber-laser-pumped Er:AYG laser at 1645 nm using 0.25% doped crystal out-performed the 0.5% doped crystal. In addition to the reported decrease in efficiency because of cooperative upconversion, a significant loss of laser output during Q-switched operation was observed and identified as two-photon absorption. This is deleterious in the short-pulse, high-intensity operational regime.

15. SUBJECT TERMS

Eyesafe laser, Solid-state laser, Infrared laser, Q-switched laser

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1. Introduction

High-peak-power, high-efficiency, eye-safe lasers operating near 1.5 μm are desirable for remote sensing applications. Recently, highly efficient operation was reported for 1645-nm Er:YAG solid-state lasers resonantly pumped with 1532-nm lasers.[1–4] Resonant pumping has the advantages of small quantum defect and small thermal load for the laser materials. High-brightness erbium fiber pump lasers at 1532 nm not only provide good absorption, but also the beam quality required for mode matching using low doping and long Er:YAG crystals. In this report, we present experimental results comparing the 0.25% and the 0.5% Er:YAG laser performance in cw and Q-switch operations. The use of a lower doping concentration reduces the deleterious effects of up-conversion and provides better thermal management.[1]

2. Experimental Set-up

The schematic for the end-pumped Er:YAG laser set-up is shown in Figure 1. An IPG Photonics TEM_{00} erbium fiber laser, which provided 20 W cw power at 1532.4 nm, was used in these experiments. This laser provides a 0.2-nm (FWHM) spectral linewidth with a 5-mm-dia, linearly polarized beam. The laser beam was shaped by a positive lens L_1 and a negative lens L_2 to match the laser mode diameter of the Er:YAG laser rod. An optical isolator (OI) prevented pump light from feeding back into the fiber laser. A half-wave plate was used to minimized the 45° beam splitter (BS) reflected loss of the pump beam. A flat input coupler mirror (IC) was coated for HT at 1532 nm (T = 95%) and HR at 1645 nm (R>99.5%).

Five 5-mm-dia Er:YAG rods were investigated: three rods (30-, 40-, and 45-mm lengths) at 0.25% erbium concentration and two rods (30- and 40-mm lengths) at 0.5%. All rods were broadband AR coated for 1.5–1.65 μm (R<0.1%). The Er:YAG crystals were placed in a copper mount and water cooled at 15°C. Output coupler mirrors (OC) were selected for optimized cw and Q-switched tests. A Brewster-cut quartz Q-switch was used for the Q-switch tests. A mirror with the same coating as the IC was used as a filter F to separate the pump beam and laser beam at the resonator output for measuring the output power.

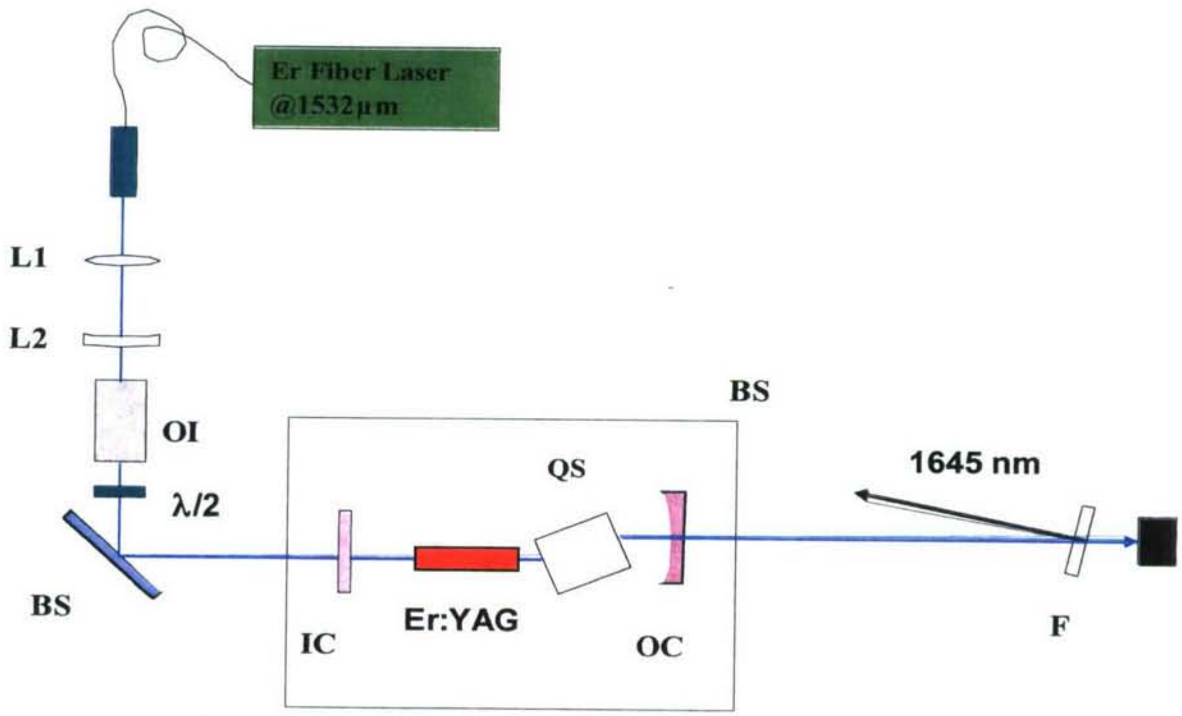

Figure 1. Schematic for end-pumped Er:YAG laser experimental set-up.

3. Experimental Results

During the initial cw laser test, a flat input-coupler mirror (IC), and an ROC = 25-cm concave R = 88% output coupler at 1645 nm was used to form a mode diameter ($1/e^2$) of ~580 μm with a cavity length of 10 cm. The lenses were adjusted to produce a pump beam diameter to match the cavity mode size. Figure 2 shows the laser performance of the five Er:YAG crystals pumped by the Er fiber laser.

The AO Q-switch was not in the cavity for cw operation. Figure 2 clearly shows that 0.25%, 40-mm and 45-mm rods outperform the other three rod samples. Its highest laser power up to 8.2 W at 1645 nm was obtained at 16 W of input power with a slope efficiency as high as 62%. There was no significant difference for the 0.25% 40-mm and 45-mm rods. However, if we compare their performances with the absorbed power instead of incident power (as shown in Figure 3), the data showed that 0.25% Er rods have a slope efficiency (>78%) that is better than the 0.5% Er rods (~50%).

For the Q-switch test, we insert the AO Q-switch into the laser cavity and increase the pump laser beam diameter to ~770 μm at the Er:YAG laser crystal, as shown in Figure 1. With a cavity length of 15.5 cm, the output coupler was replaced by a 50-cm concave 90% reflectivity mirror to better match the pump mode size. With this arrangement, the power performances of all rods were reduced about 25%. However, the 0.25% 40-mm and 45-mm Er:YAG rods still perform better than the other three rods; the 0.25% 30-mm rod also clearly performs better than the 0.5% rods. The power performance of these rods has the same order at various arrangements. Figure 4 shows the Q-switched average power versus PRF for the 0.25% 30-mm, 40-mm, and 0.5%, 30-mm rods. It also shows that the 0.25% 40-mm rod has the better average power at any PRF. The data shows that the higher the average power, the faster the power falls at lower PRF. Data also shows that the average power for the 0.25% 40-mm rod at 13 W of input power falls much faster than at 8.4 W input power. Figure 5 shows laser pulse width and pulse energy versus PRF at 13 W of pump power for the 0.25% 40-mm rod. As can be seen from the figure, 34-ns, 5.8-mJ pulses were obtained at a PRF of 400 Hz, where the highest laser peak power of 171 kW was achieved. Although shorter pulses (31-ns, 3.2-mJ) were generated by using R = 85% OC

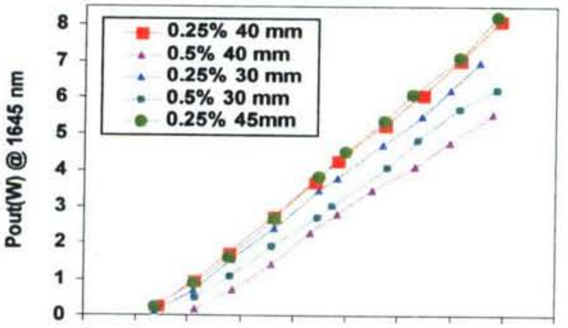

Figure 2. Cw output power performance of Er:YAG rods versus input power.

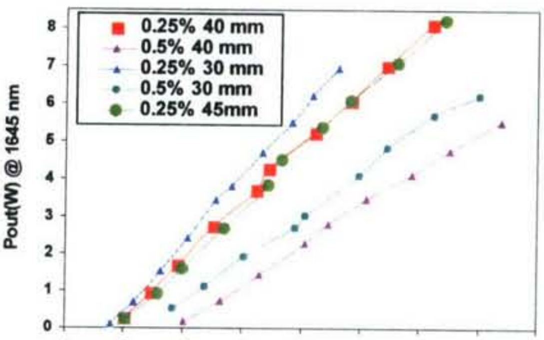

Figure 3. Cw output power performance of Er:YAG samples versus absorbed power.

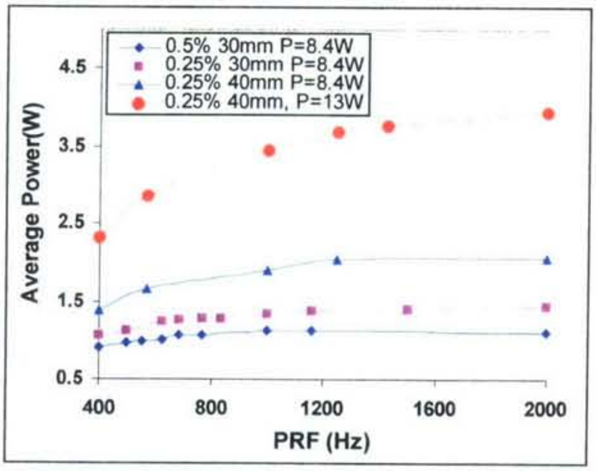

Figure 4. Er:YAG laser Q-switched average power versus PRF for all rods except the 0.5% 40-mm rod pumped with 8.4 W. Data for 25% 40-mm rod at 13 W pumping is also shown for comparison.

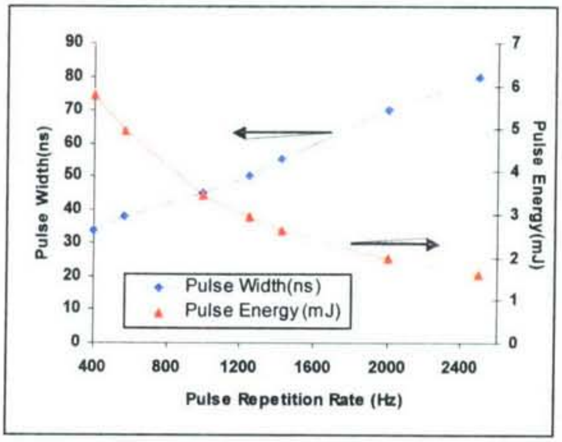

Figure 5. Er:YAG laser pulse energy and pulse width versus PRF for the 25% 40-mm rod at 13 W of pump power.

mirror with a 0.25%, 30-mm rod at 1250 Hz, the peak power (103 kW) was not as high (before the rod's coating was damaged).

During the Q-switched laser operation, much brighter green (550 nm) fluorescent emission was observed in comparison to the cw operation. The intensity of the green light gets brighter for lower PFR (higher pulse energy and shorter pulses, i.e., higher laser peak power). We believe the additional power loss for lower PRFs shown in Figure 4 may be, in part, attributed to two-photon absorption of the intracavity laser light.

4. Summary/Conclusion

In summary, our experimental results show that 0.25% Er:YAG crystals are more efficient than the 0.5% Er:YAG crystals. The 0.25% 40-mm rod may be close to optimal performance when the laser is resonantly pumped by an erbium fiber laser. CW laser power up to 8.3 W at 1645 nm was obtained at 17 W input power with slope efficiency as high as 62%. In Q-switched mode, 34-ns, 5.8-mJ pulses were obtained at a PRF of 400 Hz, where the highest laser peak power of 171 kW was achieved. An additional power loss for Q-switched operation at the lower PRFs may be attributed to the two-photon absorption of 1645-nm intracavity laser light. Further investigation is to be pursued.

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